Research on Optimal Configuration of Distribution Network Filter Based on Chaos Algorithm

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Abstract

Due to the extensive use of power electronic equipment, the harmonic content in distribution network is increasing, which poses a threat to the operation of power equipment and the reliability of power system. Power electronic devices are the main harmonic source in the power grid. With the increasing application of power electronic devices, the harmonic pollution in the power grid is becoming more and more serious. Harmonic suppression can improve the safety and reliability of equipment operation, and plays an important role in the safe and economic operation of power system. The optimal configuration of the filter is the optimal solution of the filter installation position, type, parameters and group number under the condition that the harmonic current, power grid results and parameters are known. In order to minimize the investment of the whole network filter, ensure that the total harmonic distortion rate and harmonic voltage content of each node of the network meet the harmonic standard, and make the filter operate safely, this paper gives the optimal configuration in the distribution network and the solution algorithm and mathematical model of active and passive filters. Therefore, it has become an important task to accurately analyze the harmonic distortion rate of distribution network and take corresponding treatment measures. The node admittance matrix of each harmonic of the system is established, and the network inherent structure method is used to determine the optimal location of each harmonic filter in the distribution network. Artificial immune algorithm is used to optimize the filter parameters. The method proposed in this paper can effectively suppress the harmonic voltage distortion of each node in the network, and provides a new application platform for large-scale information sharing and comprehensive research.

Keywords*: Chaos algorithm, Distribution network filter, Optimized configuration*

Ⅰ. Introduction

In recent years, a large number of capacitor banks and widely used power electronic devices have brought a large number of harmonic currents to the distribution network, and the harm caused by harmonics is becoming more and more serious, such as reducing system efficiency and power factor; Overheat power supply and consumption equipment and accelerate insulation aging; Cause malfunction of relay protection and automatic device; Affect the accuracy of electrical measuring instruments; Threaten the power quality of power grid and the safe operation of user equipment [1]. The main indicators of power system assessment of power quality are voltage amplitude and frequency. Now all countries in the world regard the limit value of grid voltage positive harmonic waveform distortion rate as one of the indicators of power quality assessment [2]. With the rapid development of power electronic technology, all kinds of new electrical equipment are more and more used, and the influence of harmonics is more and more serious [3]. Therefore, the research and analysis of harmonics has important practical significance [4]. Electric energy has become the basic energy for human survival [5]. In order to meet the growing power demand, the scale of power system must be continuously expanded, which makes the planning task of power system more and more arduous [6]. As a part of power system planning, reactive power planning of power system is the basic condition to ensure voltage quality and plays an important role in ensuring the safety, stability and economic operation of power system. Power system harmonic is one of the important indicators of power quality. Due to the development of power electronics technology in recent years, nonlinear loads such as frequency converters are widely used in power system, industry It is widely used in transportation and families, and the harm caused by

harmonics is becoming more and more serious [7]. Electric power has been widely used because of its clean and efficient advantages, and has become the lifeblood of China's national economy [8].

In order to solve the increasingly serious energy and environmental problems in China, we must change the way of energy development and utilization [9]. Using the form of distributed generation, not only can we make full use of distributed energy to provide power for users nearby, but also can run off the grid in case of large power grid failure to avoid power supply interruption and improve the reliability of distribution network [10]. Harmonic suppression is to reduce these hazards, ensure the normal operation of power supply and consumption equipment and improve social energy utilization. With the continuous strengthening of network architecture and the increasing requirements of users for power quality, the harmonic problem of distribution network has attracted more and more attention [11]. As an important part of harmonic control, the optimal configuration of distribution network filter has become one of the important research topics [12]. The optimal filter configuration is to determine the optimal location and parameters of each passive filter in the distribution network, so as to suppress the harmonic voltage distortion of each node in the network. It is a typical nonlinear hybrid programming problem [13]. At present, there are mainly nonlinear programming method, heuristic search method, simulated annealing method, genetic algorithm and so on. In this paper, the second method is used to study the optimal allocation of passive filters in distribution network by using the network inherent structure method and chaotic algorithm.

Ⅱ. Distribution Network Calculation

A. Calculation Characteristics of Distribution Network

The premise of harmonic control is to clarify the harmonic status of distribution network, so the harmonic analysis and calculation of distribution network is particularly important. The key of harmonic analysis and calculation of distribution network is harmonic power flow calculation. As an important basis for harmonic control, the accuracy of harmonic power flow calculation is related to the subsequent optimal filter configuration results. Power flow calculation is a very important calculation in distribution network. The safe operation, reliability analysis, power grid planning and optimization of power system are based on power flow calculation. Figure 1 is the schematic diagram of distribution network system links:

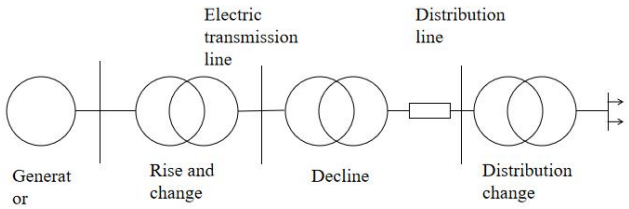

Fig.1 Schematic Diagram of Distribution Network System Links

The topology of the distribution network is generally designed in a closed loop. Except that in case of fault or load switching, most of the time operates in an open-loop state, most of them are radial, there are many branches, and there is basically no correlation between the feeders. This structure is similar to the single power supply open network. The power output from the power supply side is unidirectional power, and the power flow distribution of the power grid is determined, Therefore, the result of power flow calculation is unique; The ratio of resistance to reactance in the line is large, which leads to the increase of the condition number of the Jacobian matrix of the power grid, destroys its diagonal advantage, and shows ill conditioned characteristics in varying degrees; There are many load nodes in distribution network, and the number of branches must be less than the number of nodes, so the node admittance matrix of power network has a high sparsity; The voltage level of distribution network is not high and has small line distribution parameters, so the conductance and susceptance of line to ground can be ignored.

The research on fundamental power flow algorithm of transmission network has been lasting for a long time, and has become very mature. The reason why it is necessary to establish a set of power flow calculation model and algorithm for distribution network, which is different from transmission network, is because there are obvious differences between distribution network and transmission network in network structure. The network topology of distribution network is radial. Although the distribution network generally has a ring network in the design, in order to meet the needs of relay protection setting and fault location, the distribution network is open-loop operation in normal times. Short-term ring network operation may occur only when the load is switched or a fault occurs. The distance of each branch in the distribution network is short, the voltage is low, and the ground charging admittance of the line can often be ignored. Therefore, the distribution network is a suspended network. Aiming at the problems of convergence performance, calculation speed and stability of the fundamental power flow calculation method of transmission network in the fundamental power flow calculation of distribution network, the forward push back method is widely used in the fundamental power flow calculation of radial distribution network. Compared with simple fundamental power flow calculation, harmonic power flow calculation is more complex and difficult, and how to describe each harmonic source in the system is an important factor affecting its complexity. Therefore, harmonic power flow calculation can be mathematically reduced to the solution of all harmonic network equations and all harmonic source characteristic equations. The specific calculation method is determined according to the expression of network equations and harmonic source characteristic equations, as well as the accuracy requirements of power flow calculation in different applications.

B. Calculation Method of Distribution Network

According to the characteristics of the distribution network structure described above, the traditional methods used in the distribution network are too complex. Some studies adopt the principle of compensation technology for large lines, which makes the fast decoupling method easier to deal with the power flow calculation of the distribution network, but makes the algorithm lose the advantages of reliable convergence and small amount of calculation. When calculating the power flow of a distribution network, the first step is to optimize and number the system nodes according to certain principles. However, there are a lot of matrix operations in power system calculation. For sparse matrix and sparse vector, sparse technology is proposed, which can quickly improve the efficiency of power system calculation. In sparse technology, zeroing storage and node optimization number are two key points affecting computing efficiency. The node optimization number directly affects the sparsity of the matrix after matrix factorization, and the matrix sparsity will significantly affect the subsequent matrix operation efficiency. The forward and backward generation method suitable for power flow calculation of distribution network is used for fundamental power flow calculation. Firstly, the nodes of the network should be numbered to form the basis of the node admittance matrix.

In the calculation, the harmonic source load is considered as the injected harmonic current, and other loads can be included with equivalent constant impedance. However, loads are all over all walks of life, and the proportion of various loads also changes greatly with time, especially the capacity of electrostatic capacitors commonly installed to improve power factor, which makes it difficult to accurately determine the equivalent harmonic impedance of loads. Generally speaking, it can be divided into motor load and other loads. Its equivalent impedance is calculated respectively according to its proportion and connected in parallel to form a comprehensive equivalent impedance. For an n-node distribution network, it is assumed that h is the highest harmonic number to be treated, H represents the harmonic number, the harmonic source adopts a simplified model, and the injection current is represented by the following vector:

$$I_h = \left[i_{h1}, \ldots, i_{hi}, \ldots, i_{hN} \right]^T \quad (1)$$

The corresponding harmonic voltage of each node can be expressed as:

$$U_h = \left[U_{h1},...,U_{hi},...,U_{hN}\right]^T \quad (2)$$

The network equation of chaos calculation is:

$$I_h = Y^h U_h \quad (3)$$

Take a main line in the distribution network as the first layer, all branches on the main line as the second layer, and then take the branches as the main line, find the following branches as the third layer in turn, and continuously mark the number of corresponding layers in this order. This method is based on the pre sequence traversal order of depth first search and the node hierarchical numbering method. After the nodes of the network are numbered by the layered numbering method, the admittance matrix of the power grid can be formed according to the line parameters, and then the fundamental power flow can be calculated by the forward and backward substitution method. Finally, the harmonic analysis and calculation of the power grid can be carried out according to the calculation results of the fundamental power flow and the harmonic power flow model. The premise of analysis and calculation is to master the harmonic power flow equivalent model of each element in the distribution network. The correct harmonic equivalent model can ensure the reliability of the calculation results.

Ⅲ. Research on Optimal Configuration Method of Filter

A. Mathematical Model of Optimal Filter Configuration

The optimal configuration of the filter means that after the filter is installed, the harmonic voltage content and total voltage distortion rate of each node of the network meet the requirements of the national standard, ensure the safe operation of the filter, minimize the initial total investment cost of the filter and achieve the maximum economic benefit. Because passive filter has the advantages of simple structure, stable performance and low maintenance cost, passive filter is widely used as the most traditional filter device. As a new type of power system filtering equipment, active power filter can be divided into series type and parallel type according to different connection modes with compensation objects. In the process of practical application, parallel active power filter is often used. Parallel active power filter (APF) can eliminate harmonic current by injecting harmonic current with specific amplitude and phase into power system in parallel with harmonic source. When the output power is small, voltage source active power filter is widely used because of its low loss and high efficiency. Allowing harmonic suppression under continuous and dynamic conditions is the most prominent advantage of active power filter. The optimal configuration of filter is to optimize the installation location, installation type, number of installation groups and parameters of filter under the condition that the distribution network structure and parameters and harmonic current are known. On the premise of ensuring that the harmonic voltage content and total harmonic distortion rate of each node of the network meet the harmonic standard and the safe and reliable operation of the filter, the investment cost of the filter of the whole network is minimized. In order to meet the requirements of harmonic suppression at the least cost.

The inherent structure theory of network is used to find out the node which is most sensitive to harmonic distortion in all nodes of distribution network. Because the node admittance matrix of the system contains the network structure and parameter information of the system, the eigenvalue sensitivity of the node admittance matrix of the system is analyzed by the network inherent structure theory, and then the best position of the configuration filter is found. Considering that the optimal configuration of the filter should not only meet the requirements of voltage distortion rate, but also meet the principle of minimum cost, this paper uses a double-layer loop to optimize the position and parameters of the filter. In the inner loop, the total harmonic voltage distortion rate of each node in the network and the filter safety constraint are taken as fitness functions to guide particles to fly in the outer loop, An external array is used to store the particles that meet the distortion rate requirements. The cost is taken as the objective function to compare the solutions of all particles in the array. The solution with the lowest cost is output as the optimal solution, and the filter configuration position and parameters corresponding to the optimal solution are

output. There are many nodes in the distribution network. In order to avoid excessive search space, from the perspective of practical engineering, filters are generally installed at harmonic source nodes or their adjacent nodes, so it is not necessary to search all nodes in the distribution network.

B. Software Design of Optimal Filter Configuration

Filter is the most visual development tool at present, and has powerful database operation function. Power flow calculation includes fundamental power flow calculation and harmonic power flow calculation, which is the basis of optimal configuration calculation of distribution network filters. The fundamental power flow is solved by the method based on the node branch incidence matrix, and the harmonic power flow is solved by the direct method. The algorithm of configuring filter is the method introduced in this paper, that is, considering the centralized treatment of multiharmonic sources in a certain place. Figure 2 shows the communication of filter server:

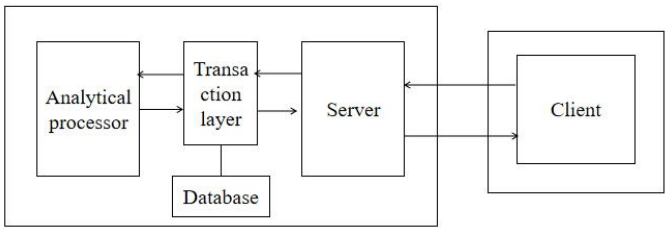

Fig.2 Communication of Filter Server

In the whole chaotic algorithm, the fitness value of particles is very important. The size of the fitness value is used to judge the advantages and disadvantages of particles and make the population evolve continuously. Each particle uses the fitness function to calculate the initial value for the first time, search according to the initial value, that is, the current value, and recalculate the fitness value of each particle after completing a cyclic iteration, This is used to judge the advantages and disadvantages of the current value of the particle, compare the individual fitness value with the searched optimal fitness value, and consider whether to replace it. After obtaining the individual optimal fitness value, compare it with the population optimal fitness value, and consider whether to replace the global optimal value of the population. The optimal location of the configuration filter is found through the network inherent structure theory and written into the filter configuration information table, and then the filter parameters of centralized governance are optimized by immune algorithm. After power flow calculation and filter optimization calculation, the optimization results of fundamental voltage, harmonic voltage, harmonic voltage distortion rate, active network loss, reactive network loss, filter optimization parameters and configuration position of each node of distribution network can be obtained. Fig. 3 is the structure diagram of filter optimization configuration software:

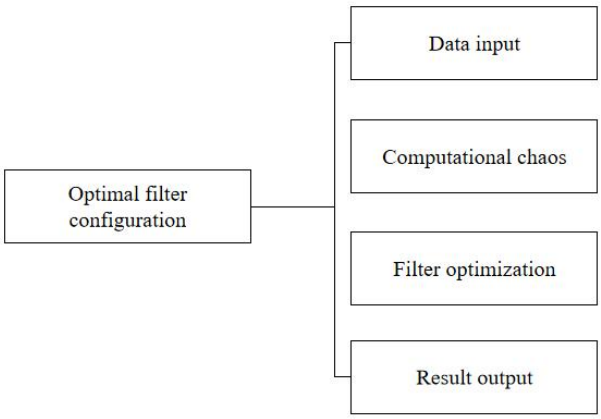

Fig.3 Structure Diagram of Filter Optimal Configuration Software

Filter optimization planning is an optimization combination problem, which minimizes the operation and investment of the whole construction. Its purpose is to find a planning scheme and meet the reliability and constraints at the same time. Chaos algorithm is an intelligent modern heuristic algorithm based on random search simulating the behavior of fish schools. The use of active power filter is a trend to suppress harmonics. The basic principle of active power filter is to detect the harmonic current from the compensation object, and the compensation device generates the compensation current with the same size and opposite polarity, so as to eliminate the harmonic in the power grid. It mainly uses foraging, clustering and tail chasing behavior as operators to achieve global optimization through individual local optimization. This algorithm has good ability to overcome local extremum and achieve global optimization. It can also solve the optimization combination problem and the characteristics of rapid convergence.

Ⅳ. Conclusion

By improving the chaotic algorithm, this paper improves the local optimization ability of the model, so that when it is applied to the configuration scheme of filter device, it not only meets the requirements of restraining harmonics, but also controls the investment cost as small as possible. The objective function is to minimize the total capacity of all passive filters in the network, the harmonic voltage and the safe operation of the filter are constraints, and the performance of reactive power compensation is considered. The filter configuration only considers the stable change of harmonic source. For the filter configuration under the non-stationary change of harmonic source, the random characteristics of harmonic source should also be considered. When planning with active filter, it is also easy to produce the problem of filter configuration. In order to ensure the optimization, the coding that ensures the basic radiation is adopted, that is, each individual is subject to radiation constraints in the process of iterative optimization and initialization, which greatly reduces the non solvability in optimization and improves the efficiency of optimization. For the location and capacity of distributed generation in distribution network, the adaptive particle swarm optimization algorithm is used to solve the optimal configuration model of distributed generation, and the location and capacity configuration scheme of distributed generation is obtained. The proposed adaptive particle swarm optimization algorithm can effectively solve the multi-objective configuration model, which is better than the distribution network economic index and operation index when considering the single type index, and the configuration scheme solved by the algorithm is compared with the configuration scheme solved by the traditional and chaotic particle swarm optimization algorithm, It can make the change of node voltage and branch active power loss of distribution network smaller, the generation cost and environmental cost of distributed generation lower, and make the operation of distribution network with distributed generation more safe and stable on the premise of meeting the economy.

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